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Reliability of the Saunders Electronic Inclinometer for the Assessment of Lumbar ROM

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**RELIABILITY OF THE SAUNDERS ELECTRONIC
INCLINOMETER FOR THE ASSESSMENT OF LUMBAR ROM**

by

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B.S. May 1988, Ithaca College

A Thesis submitted to the Faculty of
Old Dominion University in Partial
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ABSTRACT

RELIABILITY OF THE SAUNDERS ELECTRONIC INCLINOMETER FOR THE ASSESSMENT OF LUMBAR ROM

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Old Dominion University, May 1997
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Background and Purpose. The American Medical Association (AMA) advocates using the inclinometer for the measurement of spinal motion. Clinicians however, have not yet adopted this method in practice. Much controversy exists within the health care community with regard to which measurement method is the most reliable. The purpose of this study was: 1) to clarify the work that has been performed to date and 2) to examine the intrarater and interrater reliability of the Saunders Electronic Inclinometer for the assessment of lumbar flexion, extension, lateral flexion and rotation. **Subjects and Methods.** Twenty two volunteers (18 female, 4 male) were measured while standing in lumbar flexion, extension, lateral flexion and rotation. Each subject was measured on two occasions by each of two examiners. **Results.** Intrarater reliability estimates for examiner one ranged from .44 - .88 while intrarater reliability estimates for examiner two ranged from .66 - .82. As expected, interrater reliability estimates were lower ranging from .38 - .79. **Conclusion and Discussion.** Based on the preceding reliability coefficients, the authors concluded that the SEI demonstrated moderate to good reliability for the assessment of standing lumbar flexion, extension and left rotation. Standing lumbar lateral flexion and right rotation however, demonstrated poor reliability. A significant limitation

with the study was the difference in experience levels between the examiners. Both examiners underwent a one month training period prior to the beginning of the study. Examiner two had 3 years of clinical experience with the SEI. Examiner one was a final year physical therapy student while examiner two had 8 years of clinical experience. This may have accounted in part, for the variable interrater reliability estimates. Thus, results from this study suggest that the SEI should be investigated further for the measurement of the lumbar spine as well as for the cervical and thoracic spines. The SEI should be considered as a potential device for the standardization of measuring spinal motion if further studies support this conclusion.

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CHAPTER 1

INTRODUCTION

Eight out of 10 individuals will suffer a back injury significant enough to seek medical attention at some point in their lives.¹ Back injuries presently account for 30 to 40% of all worker's compensation costs.^{1,2} In 1992, the National Council on Compensation Insurance estimated that the average low back injury exceeded \$24,000/case.³ This cost can be misleading however, because 10% of the injuries typically incur 80% of the costs.⁴

These staggering figures have prompted the health care community and employers to seek prevention of these injuries. Quantifying the extent of a low back problem in a cost effective, standardized manner however, has presented a seemingly insurmountable challenge. Characteristics such as posture, strength, range of motion (ROM) and functional capacity are measured to estimate the relative functional abilities of an individual. Objective measures are necessary to develop guidelines identifying those at risk for injury.

The health care community has had particular difficulty developing an objective means to measure low back ROM. Multiple studies have been performed over several years in an attempt to quantify spinal ROM.⁵⁻⁴¹ Much controversy still exists in the literature regarding which method of evaluation is the most accurate. No single method has been universally accepted as the standard.

The AMA: Guides to the Evaluation of Permanent Impairment advocates using the inclinometer method (single or double) for assessing spinal ROM.⁴⁰ Lowery et al examined the validity of the AMA impairment rating system.⁴¹ This system, one of the most popular rating systems used to determine level of disability, relies largely on spinal range of motion. In Lowery's study, two examiners measured 14 healthy subjects using the double inclinometer method. The authors found that the impairment ratings reported by the two examiners were poorly correlated. They explained that the poor results are in part due to problems with the inclinometer technique and in part due to a decrease in ROM with age. The authors found that normal subjects had impairment ratings ranging from 2 to 38.5%. They concluded that the current impairment rating system based on spinal range of motion may not accurately reflect an individual's level of impairment.⁴¹

Thus, problems exist with our current system of assessing an individual's spinal motion. A standardized protocol for measuring spinal ROM would afford clinicians more accuracy in diagnosis, assist in documenting progress with treatment and aide in the development of standard criteria for identifying those at risk for sustaining a back injury.

Purpose

The purpose of this study was 1) to clarify the work that has been performed to date and 2) to examine the intrarater and interrater reliability of the Saunders

Electronic Inclinator for the assessment of lumbar flexion, extension, lateral flexion and rotation.

Review of the Literature

Several methods suggested for the measurement of spinal ROM include visual observation,⁵⁻⁸ radiography,⁹⁻¹⁵ tape measure,^{6,8,10-12,15-23,25-29} spondylometry,^{27,30} goniometry,^{5,8,10,16,20,23} and inclinometry.^{13,18-20,25,27,31-41}

Visual observation is the initial method typically used in an evaluation to see if a limitation exists.⁵⁻⁸ The obvious problem with this technique is the lack of objective data to quantify the extent of the limitation. Clinicians subjectively estimate an approximate percentage of limitation. Further measurement is often needed to objectively document the amount of spinal motion present.

Radiography is a second technique used in the evaluation of spinal ROM.⁹⁻¹⁵ Due to the high cost associated with this method however, as well as subject exposure to radiation, this method is not routinely employed. It is however, frequently used to validate new or modified measurement methods.⁹⁻¹⁵ Interestingly, even the results obtained with radiography, the technique used as the measurement standard, are often variable.⁹

Yochum and Rowe state that a wide variation exists for normal values of lumbar lordosis when using radiography.⁹ Lumbar lordosis is measured by drawing two lines on the radiograph along the superior end plate of L₁ and along the superior end plate of S₁. Perpendiculars are then drawn and the angle formed by their

intersection represents the lumbar lordosis angle. The authors suggest that the variability present with this method could be due to subject variation and/or variability between different examiners and techniques.⁹

One potential problem seen in a study by Burdett et al with using radiographs as the standard for comparison, is that the external measurement points must match the internal measurement points.¹⁰ Burdett et al compared four measurement techniques with radiography. They chose reference points 3 cm below the PSIS levels and 10 cm above the PSIS levels for their four external measurement techniques. The internal reference points chosen for the radiographic comparison included lines drawn along the inferior aspect of T₁₂ and along the superior aspect of S₁. The authors reported that the all four measurement techniques demonstrated poor validity when compared to radiography.¹⁰ The authors poor results can be largely explained by the variance in reference points. Different angles were measured internally and externally.

Prior to examining the tape measure,^{6,8,10-12,15-23,25-29} spondylometer,^{27,30} goniometer,^{5,8,10,16,20,23} and inclinometer^{13,18-20,25,27,31-41} as potential measurement devices for assessing spinal motion, it is necessary to discuss the various statistical measures and scales used to estimate an instrument's reliability. Four frequently cited statistics used to estimate reliability include the Intraclass Correlation Coefficient (ICC), Pearson product moment correlation coefficient (r), Coefficient of Variation (CV) and the Standard Error of Measurement (SEM).^{42,43}

The ICC is an index of agreement and is used to determine if two or more scores agree. This statistic most accurately estimates the agreement between two raters.

The ICC takes on a value from 0 to 1. The more closely the scores agree, the closer the ICC is to 1. The Pearson product moment correlation coefficient on the other hand, is an index of correlation. This is beneficial when the reliability of two different measurement devices is being examined. In this case, the actual measurements may not agree but if the two instruments demonstrate good reliability, there will be a strong positive correlation between the two measurements. The Pearson product moment r takes on a value from -1 to +1.^{42,43}

The CV reflects the variability within a sample. This statistic is the standard deviation expressed as a percentage of the mean. The CV is useful in determining the stability of subject responses but does not truly reflect the measurement error. A measured characteristic that is highly variable among subjects will produce a high CV. This does not necessarily mean that the measurement device produced unreliable results.^{42,43}

Lastly, the SEM is an index of measurement error. This statistic is a function of the standard deviation and the reliability coefficient. If rater reliability is used, the SEM reflects the extent of expected error in different raters' scores. The SEM is reported in the units of the measurement. This statistic allows the researcher to determine Confidence Intervals for similar measurements. Thus, a clinician could expect that 95% of the time, a measurement would fall within a certain range.^{42,43}

Finally, researchers estimate the reliability of measurements based on various scales. The reader must be aware of the scale before a clinical judgement can be made. For example, Frost et al used the following scale, $>.80$ demonstrates good reliability

while $< .80$ demonstrates poor reliability. They reported good reliability ($r = .82$) for the measurement of trunk flexion and poor reliability ($r = .70$) for the measurement of trunk lateral flexion.¹⁷ These results could be interpreted differently depending on the scale. Portney et al⁴³ suggest values $> .75$ demonstrate good reliability, $.50 - .75$ demonstrate moderate reliability and $< .50$ demonstrate poor reliability. In this case, the trunk flexion measurement would demonstrate good reliability while the trunk lateral flexion measurement would demonstrate moderate reliability. The reader must be aware of the scale on which the researchers are basing their conclusions. Thus, caution must be used in examining the following studies because direct comparison of the results is often not feasible.

A third device suggested for the evaluation of spinal ROM is the tape measure. This has been utilized in four different ways including the fingertip-to-floor method,^{6,8,16-20} the skin distraction method,^{10,12,15-19,21-23,25-28} the skin attraction method,^{16,17,25,29} and the plumbline method.^{11,18,26}

The fingertip-to-floor method^{6,8,16-20} is used to measure trunk flexion and lateral flexion. It involves measuring the distance from the subject's middle finger to the floor with the subject in a forward or laterally flexed position. Some authors argue however, that because one can not isolate spinal motion from hip motion, that this test should be used only as a means to assess general flexibility, not as a means to measure trunk flexion.¹⁶

Frost et al studied the fingertip-to-floor method for measuring trunk flexion and lateral flexion. The authors modified the technique used for assessing trunk flexion by

having the subjects stand on a small stepstool. The distance from the tip of the middle finger to the top of the stepstool was then measured. They reported good reliability for trunk flexion ($r=.82$) and poor reliability for lateral flexion ($r=.70$). The authors stated that the reliability estimates represent the variability of three characteristics: raters, days and successive repetitions. Each of 24 subjects was measured three times by three examiners on two separate days.¹⁷

Merritt et al also studied the fingertip-to-floor method for the assessment of trunk flexion and reported poor reliability. Results, reported as Coefficients of Variation (CV's) were 83% and 76.4% for interexaminer and intraexaminer reliability respectively. The interexaminer reliability was assessed based on 25 subjects, each subject was measured three times on three different days by three different examiners. Another 25 subjects were measured for the intraexaminer reliability, each measured three times by the same examiner on three different days.¹⁸

Gill et al examined the fingertip-to-floor method as a means to assess trunk flexion. Ten normal subjects were measured in standing. One examiner performed 2 measurements on each subject on 2 occasions during the same day. The repeatability of the measurement was reported as a Coefficient of Variation ($CV=14.1\%$). The authors concluded that the fingertip-to-floor method demonstrated poor repeatability.¹⁹

Finally, Klein et al examined the reliability of the fingertip-to-floor method as a means to assess lumbar lateral flexion as part of a larger study. Twenty five male subjects (8 with LBP and 17 normals) were measured two times by one examiner. The subjects began in neutral standing. When they achieved full lateral flexion, the distance

from the tip of the middle finger to the floor was measured. The authors reported intraexaminer reliability estimates of .71 and .80 for (L) and (R) lateral lumbar flexion respectively.²⁰

Differences in the statistical analyses of the above studies make direct comparison of the results impossible. It is clear however, that the results obtained with this technique are variable. This, in combination with the inability to isolate specific spinal motion, has prompted clinicians to use the fingertip-to-floor method primarily as a means to assess the overall flexibility of the spine.¹⁶ Clinicians have continued to search for a more reliable means to objectively document lumbar ROM.

The second suggested technique involving the tape measure is the skin distraction method.^{10,12,15-19,21-23,25-28} This method was originally described by Schober in 1937 as a means to measure lumbar flexion.²¹ The Schober technique involves marking two points on the spine, one at the lumbosacral junction and the second 10 cm above. The distance between the two points is first measured with the subject standing erect and then again with the subject in a forward flexed position. The difference between the two measurements represents lumbar flexion.

This technique has been modified over the years to improve the estimates of lumbar flexion,^{10,12,18,19,22,23,25-27} to include thoracic flexion,^{16,28} to measure lateral flexion^{15,18,26,27} and to measure spinal rotation.¹⁷ The studies examining lumbar flexion will be addressed first.

Macrae and Wright compared the Schober technique with a modification of Schober's method.²¹ The authors varied the reference points using a point 10 cm above

and a point 5 cm below the lumbosacral junction. They examined the validity of the two methods in comparison with radiographs. The correlation coefficients reported for 11 subjects were .90 and .97 for the Schober and modified techniques respectively. The authors concluded that their modified technique, using 15 cm as the starting length of the lumbar spine produced less error than Schober's technique using 10 cm as the starting length of the lumbar spine. The technique described by Macrae and Wright²¹ is now described in the literature as the modified Schober method.^{18,25-27}

Gill et al examined the modified Schober method for assessing standing and sitting lumbar flexion, extension and erect posture.¹⁹ Ten normal subjects were measured by one examiner. The same landmarks were used as described by Macrae and Wright.¹² The subjects performed lumbar flexion, erect posture and lumbar extension in standing and sitting. Each subject was then measured again in the same sequence following a ten minute rest interval. The repeatability estimates, expressed as Coefficients of Variation (CV's), were .9%, 2.8% and 3.2% for standing lumbar flexion, extension and erect posture. The CV's for the same motions in sitting were 1.5%, 2.9% and 4.2%. The authors concluded that the modified Schober method demonstrated good repeatability and recommended its use for routine, clinical evaluation of lumbar spinal motion.

Further modifications have been made to the Schober and modified Schober techniques for the assessment of lumbar flexion.^{10,22,23,25} Van Adrichem and van der Korst examined the technique using the spinous process of L₅ and a point 15 cm above

this as reference points. They investigated points 5,10,15, and 20 cm above L₅ in five healthy men, ages 20-25, and found that most motion occurs within the 15 cm point.²²

To determine intrarater reliability, one examiner measured each of 5 subjects on seven occasions at one week intervals. Results were expressed as percentages of the mean. The variation from the mean for the 15 cm landmark ranged from 3-8%. The authors suggested that the actual length of the lumbar spine is closer to 15 cm and that movement above this point is negligible. The authors concluded that the point 15 cm above was superior to that of 10 cm used by Schober²¹ and Macrae and Wright.¹²

Fitzgerald et al, using the Schober method²¹, reported an interobserver reliability of 1.0 for lumbar flexion.²³ Seventeen healthy volunteers were measured by two examiners on three occasions. Careful review of their method however, reveals a discrepancy with the Schober technique.²¹ The authors used the superior aspects of the iliac crests as the inferior reference point. The superior aspects of the iliac crests are located at the L₄ level,²⁴ not at the lumbosacral junction used by Schober.²¹ Thus, this study again presents a slight modification of the Schober method.²¹

Burdett et al further modified the Schober method by varying the reference points. The authors chose a distal point 3 cm below the PSIS levels and a proximal point 10 cm above the PSIS levels. Two therapists examined 23 healthy volunteers to determine the reliability of the modified technique. The authors reported poor interexaminer reliability ($r=.71$, $ICC=.72$).¹⁰

Finally, Williams et al modified the technique of van Adrichem and van der Korst,²² using the PSIS levels and a point 15 cm above this as their two reference

points. Three examiners measured lumbar flexion in 15 subjects with low back pain. The test-retest reliability coefficients for the three examiners ranged from $r = .78$ to $.89$. The ICC for interrater reliability was $.72$. The authors concluded that their technique was reliable. This method is now referred to in the literature as the Modified-Modified Schober method (MMS).²⁵

Thus, as noted in the studies above, results ranging from poor to high reliability have been reported using the Schober method. This high degree of variability can be explained, in part, by inconsistencies in choosing reference points and the lack of a standard reproducible starting position. There is also the potential for significant subject and examiner variability when measuring lumbar flexion as well as all other motions of the spine. As a result, the literature is extremely confusing. It is often impossible to directly compare many of the studies that have been performed because of inconsistencies in the method employed.

In addition to its use in the measurement of lumbar flexion, the skin distraction technique has further been modified to include the measurement of both thoracic and lumbar flexion.^{16,28} This involves marking two points on the skin, one at the S_1 level and a second point at the C_7 level. The distance between the two points is measured with the subject first in a neutral standing position and then again with the subject in forward flexion. The difference between the two measurements represents thoracic and lumbar flexion combined. Although this technique has been suggested, no data was found regarding its reliability.

A third modification of the skin distraction technique was introduced to assess lateral flexion.^{15,18,26,27} This technique, originally described by Moll and Wright,²⁶ involves placing two points on the lateral trunk. One point represents the intersection of a horizontal line through the xiphisternum with the coronal line and the second point represents the intersection of a horizontal line through the highest point on the iliac crest with the coronal line. The distance between the two points is then measured with the subject first in neutral standing and then again with the subject in a laterally flexed position. The difference between the two approximated or distracted points represents lateral flexion. The authors suggest using the distraction distance to increase accuracy when measuring obese subjects.

Moll et al tested the reliability and validity of the Moll and Wright technique²⁶ for the assesment of lateral trunk flexion. Intraobserver reliability was assessed by measuring one subject over ten successive days. CV's of 6.1% and 6.6% were reported for right and left lateral flexion respectively. The interobserver reliability ($r=.68$) was estimated with 2 testers measuring 17 volunteers. Lastly, the validity of the lateral flexion technique was assessed through comparison with radiology in 43 volunteers (36 normals and 7 with ankylosing spondylitis). Lateral flexion was defined radiologically as the angle formed by two lines drawn through the lower borders of T₉ and L₅. A positive correlation ($r=.79$) was found between the approximation measurement and the lateral flexion angle. The authors concluded that their method of measuring lateral flexion of the spine was acceptably reliable.¹⁵

Reynolds²⁷ also examined the reliability of the skin distraction technique described by Moll et al.¹⁵ Results of the two studies however, were very different even though identical landmarks were used. Intraobserver reliability was tested on one subject over 10 successive days. CV's of 15.75% and 12.91% were reported for right and left lateral flexion respectively. Interobserver reliability was based on two observers measuring 10 subjects. Reliability estimates of .41 and .31 were reported for right and left lateral flexion respectively.²⁷

Merritt et al¹⁸ modified the Moll and Wright²⁶ skin distraction method by changing the upper mark. They kept the lower mark at the point where the frontal line crossed the iliac crest, but they modified the upper mark to a point 20 cm above this. The rationale was that less error in identifying the upper reference point would yield more accurate results. Two other differences included changing the subject position from neutral standing with hands at sides to neutral standing with hands clasped behind the head, and consistently using the distraction distance rather than the approximation distance to represent lateral flexion. The Coefficients of Variation for right and left lateral flexion were 11.9% and 10.2% respectively for interexaminer reliability (three testers, 25 healthy volunteers), and 8.9% and 9.5% for intraexaminer reliability respectively (one tester, 25 additional healthy volunteers).¹⁸

Much variability exists between the above three authors^{15,18,27} in the assessment of this one motion of the spine. This is comparable to the variability that exists between all other techniques described in the literature regarding measurement of spinal motion. In this case however, the above three studies are very similar in their

methods but discrepancies still exist in their results. Thus, it is critical that variability due to subjects and examiners be minimized. This is possible only through standardization of patient positions, reference points and examiner training.

Finally, a fourth modification of the skin distraction method was introduced by Frost et al to assess combined thoracic and lumbar rotation.¹⁷ This technique involves measuring the distance from the greater trochanter of one hip to the opposite posterior clavicular prominence. The initial measurement is taken with the subject in a neutral sitting position. Then as the subject achieves maximum trunk rotation, the second measurement is taken. The difference between the two measurements represents rotation.

Twenty four subjects were each measured three times by three examiners on two separate days. The reliability estimate based on the above three characteristics was poor ($r=.11$). The reliability based on the rater alone was also poor ($r=.13$). The authors concluded that random error accounted for the inconsistencies with this technique and they suggested that this technique be used only to indicate the presence or absence of pain with movement.¹⁷

A third use of the tape measure, the skin attraction method,^{16,17,25,29} has been proposed as a means to measure lumbar extension and combined thoracic/lumbar extension. This technique involves measuring the distance between two points on the posterior spine with the subject first in neutral standing and then again with the subject in standing extension. The difference between the two measurements represents trunk extension.

Frost et al examined the reliability of this method for the measurement of combined thoracic and lumbar extension.¹⁷ The reference points chosen were the spinous process of C₇ and the PSIS levels. Two measurements were taken, one with the subject in neutral standing and the second in maximal spinal extension.

Twenty four subjects were each measured three times by three examiners on two separate days. The reliability estimate representing the variability across raters, days and successive repetitions was poor ($r=.45$). The estimate based solely on the rater was better ($r=.79$), but still poor based on the authors' definitions. They concluded that the results might be improved by changing the landmarks. The authors urged caution however, because any measurement error could be significant given the small amount of motion that is available.¹⁷

Beattie et al examined the skin attraction method for assessing lumbar extension using landmarks 5 cm below and 10 cm above the PSIS levels. Two groups of subjects (100 without LBP and 100 with LBP) were measured to determine intrarater reliability. Each subject was measured twice by one examiner. The ICC's ranged from .90-.95 with no significant difference reported for subjects with or without LBP. Interrater reliability was assessed through the measurement of eleven normal subjects. Each subject was measured twice by two examiners with a reported ICC of .94. The authors concluded that this method is reliable for the assessment of lumbar extension.²⁹

Finally, Williams et al also examined the reliability of the skin attraction method for measuring lumbar extension. Fifteen subjects with LBP were measured two times on two separate days by three examiners. The PSIS levels and a point 15 cm

above were chosen as landmarks. The test-retest reliabilities ranged from .69 to .91 and the ICC for interrater reliability was .76.²⁵

Again, a significant degree of variability exists between authors with regard to a proposed measurement technique for assessing spinal motion. Perhaps the results with the skin attraction method could have been improved with standardization of the method used. Given the small degree of available motion, even a slight error can produce highly variable results.

The final technique involving the tape measure is the plumbline method.^{11,18,26} This was proposed by Moll et al as a means to measure spinal extension.¹¹ Two points are marked on the lateral trunk and a plumbline is then dropped from the superior point to the inferior point. The subject begins in neutral standing with hands clasped behind the head. Once maximum spinal extension is achieved, the horizontal distance between the inferior point and the tip of the plumbline is measured. This distance represents spinal extension.

Moll et al defined the superior landmark as the intersection of a horizontal line through the xiphisternum with the coronal line. The lower mark was defined as the intersection of a horizontal line through the highest point on the iliac crest with the coronal line. The intraobserver error (CV=4.7%) was estimated based on one examiner measuring one normal subject over ten alternate days. The inter-observer error was based on two examiners measuring 14 subjects (2 with ankylosing spondylitis, 1 with lumbar disc prolapse and 11 normals). Measurements were taken from right and left sides so a total of 28 measurements were taken by each examiner.

A correlation coefficient of $+0.93$ was reported. Thus, the authors concluded that the method was reliable.¹¹

Moll et al also evaluated the validity of the plumbline method. Twenty four subjects (18 normals and 6 with ankylosing spondylitis) were measured. The distance between the two landmarks was measured as noted above and then compared with the angle of thoraco-lumbar extension measured radiographically. The authors defined thoraco-lumbar extension as the angle subtended by a line drawn through the upper border of T₁₂ and the lower border of L₅. A positive correlation of 0.75 was reported for the two methods. Thus, the authors also concluded that the plumbline method demonstrated validity for measuring spinal extension.¹¹

Merritt et al also examined the reliability of the plumbline method.¹⁸ The authors modified the landmarks slightly. The lower mark remained at the intersection of a horizontal line through the highest point on the iliac crest with the coronal line but the upper mark was changed to a point 20 cm above the lower mark. The interexaminer reliability (CV=9.5%) was based on the assessment of 25 subjects. Each subject was measured three times on three different days by three different examiners. Another group of 25 subjects was measured for the intraexaminer reliability (CV=7.3%). Each subject was measured three times by the same examiner on three different days. The authors concluded that the plumbline method was a reliable means to measure lumbar extension.

The last two studies examining the plumbline method demonstrate more consistent findings than the previous tape measure methods reviewed. There is still

however, variability between authors regarding the choice of reference points. Clearly, significant discrepancies exist with this measurement tool, not only in the methods employed but also in the results obtained with its use. This variability has driven clinicians to continue searching for a more accurate instrument with which to measure spinal motion.

A fourth technique proposed for the assessment of spinal flexion and extension is the spondylometer.^{27,30} This instrument is composed of two angled brass rods that are hinged, with a knob at one end and a protractor at the other.³⁰ The protractor is placed over the sacrum and the free end is placed over the C₇ spinous process. The standing subject then flexes or extends and the angles are measured.

Hart et al reported excellent clinical results using the spondylometer over a period of 10 to 26 years. The authors did not use a controlled experimental design but they presented clinical data on the progress of 27 patients over the course of several years. Their subjects included 24 males and 3 females with ankylosing spondylitis. They concluded that the spondylometer was a fast, simple method for assessing spinal flexion and extension that produced reliable results when used by one or several examiners.³⁰

Reynolds et al assessed the reliability of the spondylometer using the method noted in the previous study. The authors tested intra-observer reliability by measuring one subject over 10 sessions. Results, reported in CV's were 7.01% for flexion and 12.65% for extension. Two examiners measured 10 subjects to evaluate inter-observer reliability. The reliability estimates, reported as Correlation Coefficients, were .76 and

.87 for thoracolumbar flexion and extension respectively. The authors concluded that the spondylometer is a simple, quick and reliable method for assessing spinal ROM. The limitation with the instrument however is its inability to measure region specific ROM.²⁷

Thus, spondylometry does appear to produce reliable results when used by one or more examiners. The problems with the device however, including its inability to measure region specific spinal mobility and its inability to be adapted for the measurement of lateral flexion and rotation, have led clinicians to seek a more versatile device for assessing spinal mobility.

The fifth device suggested for the assessment of spinal ROM is the goniometer.^{5,8,10,16,20,23} This instrument is widely accepted as a reliable means to measure upper and lower extremity ROM.^{16,31} The complex nature of the spine however, has made measurement of this region more difficult. The various types of goniometers that have been suggested for the assessment of spinal motion include the standard goniometer,^{5,8,10,16,20,23} gravity goniometer,¹⁰ parallelogram goniometer,¹⁰ fluid goniometer¹³ and pendulum goniometer.^{18,27}

The standard goniometer has been used to measure flexion,^{8,10} extension,^{8,10,23} lateral flexion,^{8,16,23} and rotation^{8,16,20} of the thoracolumbar and lumbar spines. The following information is categorized according to the motion measured.

Burdett et al proposed two different ways to measure lumbar flexion with a standard goniometer.¹⁰ One involved direct measurement and the second involved indirect measurement off a photograph. Twenty three normal subjects performed

flexion in sitting such that their shoulders touched their thighs, or until they reached maximum flexion. Two wooden pointers were mounted perpendicularly to their backs at points 3 cm below and 10 cm above the PSIS levels.

With the subject in maximum flexion, the angle between the two pointers was measured with the goniometer, first directly and then indirectly off a photograph. The interrater reliability estimates for the direct technique were $r=.85$ and $ICC=.85$. The photographic measurement produced similar results, $r=.87$ and $ICC=.87$.¹⁰

Burdett et al also examined the validity of this technique by comparison with radiography. The authors defined the internal lumbar flexion angle as the angle formed by lines drawn along the inferior border of T₁₂ and along the superior border of S₁. They then compared the angle obtained radiographically with both external goniometric measurements. The results were poor for both techniques: direct ($r=.70$, $ICC=-.09$) and indirect ($r=.76$, $ICC=-.05$). Careful review of their method however, reveals that the angles measured internally did not match the angles measured externally. The authors suggested either changing the external reference points or searching for a more valid external measurement device.¹⁰

Fitzgerald et al examined the reliability of the standard goniometer as a means to assess thoracolumbar extension. Seventeen subjects were measured in standing by two examiners. The axis of the goniometer was positioned at the iliac crest, the stationary arm was aligned perpendicular to the floor and the moving arm was projected along the midaxillary line. As the subjects reached end range extension the angle was measured. An interrater reliability estimate of $r=.88$ was reported. The

authors concluded that this is a reliable technique for assessing thoracolumbar extension.²³

Burdett et al also examined the reliability of the standard goniometer for the assessment of lumbar extension.¹⁰ Using the same method noted with their assessment of lumbar flexion, twenty three subjects were measured in prone hyperextension on a hinged table. Both direct and indirect measurements were again taken. The results were poor for both techniques: direct ($r=.77$, $ICC=.75$) and indirect ($r=.81$, $ICC=.78$). The authors suggested that the skin movement beneath the pointers which occurred during extension may have accounted for the results.

The authors also examined the validity of the lumbar extension measurement via comparison with radiography. As noted previously, different angles were measured internally and externally. Thus, the validities were poor for both techniques: direct ($r=.51$, $ICC=-.63$) and indirect ($r=.60$, $ICC=-.62$).¹⁰

The third motion that has been measured with the standard goniometer is thoracolumbar lateral flexion. This technique has been consistently described by various authors,^{8,16,23} however its reliability was reported by only one author.²³

Fitzgerald et al assessed 17 subjects to determine the reliability of this technique. Each subject was assessed in standing by two examiners. The axis of the goniometer was positioned at the lumbosacral junction, the stable arm was aligned perpendicular to the floor and the moving arm was projected to the spinous process of C₇. As the subject reached end range lateral flexion, the angle was measured. The interrater reliabilities reported for right and left lateral flexion were $r=.76$ and $r=.91$

respectively. No explanation was offered for the difference in reliabilities. The authors concluded that this method is a reliable means for assessing thoracolumbar lateral flexion.²³

Lastly, the standard goniometer has been used in the assessment of thoracolumbar rotation.^{8,16,20} As noted with lateral flexion, the reliability of this technique was only reported by one author.²⁰

Klein et al examined the intratester reliability for right and left rotation. Twenty five normal subjects were assessed in sitting. The axis of the goniometer was centered over the subject's head, the stable arm was aligned with the acromion processes and the moving arm was projected along the subject's iliac crest. With arms folded across the chest, the subjects performed trunk rotation. When the subject reached end range rotation, the angle was measured. The results were high for both right ($r=.90$) and left ($r=.91$) rotation.²⁰

Thus, the standard goniometer has been shown to be reliable for the measurement of all motions of the lumbar spine. Inconsistencies however, have been reported by various authors. This has prompted the development of more precise, region specific goniometers for the measurement of spinal mobility. These include the gravity,¹⁰ parallelogram,¹⁰ fluid,¹³ and pendulum^{18,27} goniometers.

The gravity goniometer measures the angle between the vertical plane and the tangent to the spine at the point of measurement.¹⁰ The parallelogram goniometer directly measures the angular difference between two points on the spine.¹⁰ The fluid⁶

and pendulum^{18,27} goniometers are also referred to as mechanical inclinometers and they will be discussed in the next section.

Burdett et al assessed the reliability of both the gravity and parallelogram goniometers for the measurement of lumbar flexion and extension. The method was similar to that used by the authors previously in their examination of the standard goniometer. Twenty three subjects were measured in standing for the flexion measurement and in prone hyperextension for the extension measurement. Two points were marked on the spine, one 3 cm below the PSIS levels and the second 10 cm above the PSIS levels.¹⁰

The interrater reliability estimates for the gravity goniometer were as follows: lumbar flexion ($r=.93$, $ICC=.91$) and lumbar extension ($r=.72$, $ICC=.71$). The results for the parallelogram goniometer were similar: lumbar flexion ($r=.93$, $ICC=.92$) and lumbar extension ($r=.64$, $ICC=.60$). The lumbar extension measurements were the least reliable with both instruments. The authors concluded that they preferred the gravity and parallelogram goniometers over the tape measure or standard goniometer because of their versatility in measuring regional spinal motion.¹⁰

The validity of the two goniometric techniques was also assessed as noted previously, by comparison with radiography. The results again were poor due to the measurement of different angles internally and externally. The validity estimates using the gravity goniometer were ($r=.73$, $ICC=-.11$) for lumbar flexion and ($r=.15$, $ICC=-.73$) for lumbar extension. The parallelogram goniometer produced similar

results: ($r=.46$, $ICC = -.19$) for lumbar flexion and ($r = .24$, $ICC = -.71$) for lumbar extension.¹⁰

Three different types of goniometers have been presented thus far as potential tools for assessing spinal motion. The reliability of all these devices has been relatively high for the assessment of some or all motions of the spine. Portney et al⁴² suggest the following reliability coefficient values: $>.75$ is considered good reliability, $.50-.75$ is considered moderate reliability, and $<.50$ is considered to demonstrate poor reliability. Thus, the standard goniometer, gravity goniometer and parallelogram goniometer have all been shown to be moderately to very reliable in all the above cases according to the above definitions.

Regardless of their high reliabilities, only the standard goniometer has been shown to be reliable for the assessment of all motions of the thoracolumbar spine. This device has been criticized however because of its inability to measure region specific motion. As a result, clinicians have continued the search for one instrument that can isolate and reliably measure all motions of the thoracic and lumbar spines.

Finally, the instrument that has afforded the most attention recently is the inclinometer.^{13,18-20,25,27,32-41} This device varies in type and design but gravity is the consistent principle on which it operates.⁴⁰ The two main types include the mechanical inclinometer^{13,18-20,25,27,32-37,40,41} and the electronic inclinometer.³⁸⁻⁴¹

The mechanical inclinometer^{13,18-20,25,27,32-37,40,41} has a starting or zero position that is indicated by a weighted needle, a fluid level, or a pendulum, thus the device is frequently referred to as a fluid¹³ or pendulum^{18,27} goniometer. As the inclinometer is

moved in space it reads an angle with respect to the starting position. An electronic inclinometer³⁸⁻⁴¹ contains a gravity sensor that determines the angle in which the device is placed in reference to a zero, or starting position. The electronic device must be "zeroed" before a measurement can be taken. This procedure involves calibrating the instrument at zero at a starting position such as on an individual's spine while in neutral stance or along the surface of a table. Then as the instrument is moved, it displays an angle in reference to the starting position.

Differences exist among investigators regarding the most accurate protocol for using the inclinometer.^{13,18-20,25,27,32-41} Suppose for instance, that one wanted to measure an individual's lumbar lordosis. The basic procedure for taking measurements with the inclinometer involves marking reference points on the dorsal spine. One point would be marked at the lumbosacral junction and a second would be marked at the thoracolumbar junction. The inclinometer would be calibrated at its starting position, the subject positioned, the inclinometer placed in the sagittal plane at each point and readings would be taken. The difference between the two readings would represent the lordosis angle.

Authors differ with regard to the type and number of inclinometers used, the choice of reference points, and the subject position.^{13,18-20,25,27,32-41} Some authors advocate using the double inclinometer technique^{13,19,20,25,33-35,37,39-41} in which both points are measured simultaneously while others suggest using the single inclinometer technique^{13,27,33,36,38-41} in which both points are measured with the same instrument. The majority of studies performed have utilized the mechanical inclinometer^{13,18-}

^{20,25,27,32-37,40,41} but the electronic inclinometer³⁸⁻⁴¹ is gaining in popularity. The mechanical inclinometer techniques will be examined first.

The first author to describe using a single pendulum goniometer, or inclinometer to assess standing posture, thoracolumbar flexion and thoracolumbar extension was Loebl in 1967.³² This inclinometer, specifically designed for measuring the spine, consisted of a weighted needle and a dial divided into degrees. The subjects were marked at four points: the spinous processes of T₁, T₁₂, a point midway between T₁ and T₁₂, and S₁. Intra-tester reliability was tested on nine subjects, each measured on five occasions at random intervals. The variabilities between measurements ranged from 5 to 23 degrees, or an average of 14 degrees for the total range of spinal movement. Possible reasons suggested for the inconsistencies included inaccuracies in reading the inclinometer, inaccuracies in marking the reference points, variation in spinal flexibility and variation in subject cooperation.

To evaluate the true instrument error more accurately, Loebl measured the most inconsistent subject on a daily and on an hourly basis using the same skin markings. With the more controlled assessments, variations between measurements were decreased to 11 degrees and 4 degrees respectively. The author concluded that the true accuracy of the method was represented by the 4 degree error, or 3.4% variability.

Loebl then presented normal values in ten year intervals for standing thoracic and lumbar postures, sitting thoracic and lumbar flexion, and prone thoracic and lumbar extension. These values were obtained from 176 normal subjects.³²

Reynolds assessed the intra- and inter-tester reliability of the pendulum goniometer, or inclinometer used by Loeb³² for the assessment of thoracolumbar flexion, thoracolumbar extension, thoracolumbar lateral flexion and lumbar lateral flexion.²⁷ The instrument was modified slightly by decreasing the width of the feet from 9 cm to 5 cm. All motions were measured with the subjects standing. The author used three different reference points including the spinous process of C₇, a point 10 cm above the T₁₂-L₁ junction and the sacrum.

Intra-tester reliability was estimated from 10 measurements taken on one subject during one day. Results, reported in Coefficients of Variation, were 7.18%, 23.49%, 2.83%, and 9.29% respectively for thoracolumbar flexion, thoracolumbar extension, (R) and (L) thoracolumbar lateral flexion; and 20.29%, 25.06% respectively for (R) and (L) lumbar lateral flexion.

Inter-tester reliability was based on two examiners measuring 10 subjects. Results, reported as Correlation Coefficients were .77, .75, .78, and .73 for thoracolumbar flexion, thoracolumbar extension, (R) thoracolumbar lateral flexion and (L) thoracolumbar lateral flexion. The author concluded that this technique was a valuable method for objectively reporting spinal ROM and that further training and experience with the inclinometer would improve the reliability of the results.²⁷

Merritt et al examined the intra- and interexaminer reliability of the single inclinometer method introduced by Loeb³² for the assessment of lumbar flexion and extension.¹⁸ Due to difficulty with identification of the T₁₂ spinous process, the upper

reference point was changed to a point 15 centimeters above S_1 . The lower reference point remained at the S_1 level.

Intraexaminer reliability was tested on 25 normal subjects. Each subject was measured on three occasions by three examiners on three separate days. Lumbar flexion was measured while the subjects were sitting and lumbar extension was measured while the subjects were prone. Results, reported in Coefficients of Variation were 13.4% for lumbar flexion and 50.7 % for lumbar extension.

Interexaminer reliability was tested on 25 different normal subjects. Each subject was measured one time by three different examiners on three separate days. The mean Coefficients of Variation for lumbar flexion and extension were reported as 9.6% and 65.4% respectively.

The explanation offered by the authors regarding the high discrepancy rates for lumbar extension was due to the small radius of the extended spine versus the flexed spine. Regardless of the high variability for lumbar extension however, the authors concluded that the single inclinometer technique did show promise as a means to assess spinal ROM with further practice and training.¹⁸

Breum et al examined the intra- and interexaminer reliability of a single inclinometer, the BROM II, designed specifically for assessing spinal motion. They then examined the concurrent validity of the BROM II in comparison with the double inclinometer technique.³³

Forty seven asymptomatic individuals were measured by two examiners using the BROM II for lumbar flexion, extension, lateral flexion and rotation. Subjects were

measured by each examiner two times on two occasions in the same day. Landmarks for the BROM II were the T₁₂-L₁ interspace and the S₁ tubercle. Subjects were marked with indelible marker to avoid errors associated with palpation. All measurements were taken with the subject standing with the exception of rotation which was measured in sitting. The Intraclass Correlation Coefficient's reported for intraexaminer reliability were .91, .63, .56, .57, .92, and .89 for flexion, extension, left rotation, right rotation, left lateral flexion and right lateral flexion respectively. ICC's for interexaminer reliability were .75, .63, .69, .61, .27, and .65 for the above motions respectively.

Lastly, concurrent validity was evaluated by comparison with the double inclinometer (DI) technique.³³ Two fluid-filled mechanical inclinometers were used. One examiner performed two measurements with each device on each of 47 subjects on two occasions in the same day. The method for the DI technique was the same as that used by Keeley et al.³⁴ Concurrent validity results, reported in ICC's were .75, .63, .69, .61, .27, and .65 for flexion, extension, left lateral flexion, right lateral flexion, left rotation and right rotation respectively.

The authors concluded that the BROM II is reliable for the measurement of lumbar flexion and lateral flexion in asymptomatic patients. They recommended further investigation of this device however before its use clinically with patients and prior to the measurement of lumbar extension and rotation.³³

The following study examined both the single and the double inclinometer techniques. Mayer et al compared lumbar flexion and extension using both single and

double mechanical inclinometers. The validity of the double inclinometer (DI) technique was also examined via comparison with radiography. The reference points for the inclinometer measurements were the T₁₂-L₁ junction and the sacrum.¹³

Six normal subjects were measured in standing for comparison of the single and double inclinometer methods. The DI method involved measuring each point simultaneously with two separate inclinometers while the subject maintained lumbar flexion and extension. The single inclinometer (SI) method required two examiners, one placed their hands about the anterior and posterior aspects of the iliac crests to form a surface from which to measure the sacral point and the second performed the measurements with subjects flexed and extended. The authors reported no difference between the two methods. The mean pelvic flexion motion obtained using the DI method was $63^{\circ} \pm 14.8^{\circ}$ and $63^{\circ} \pm 15.1^{\circ}$ using the SI method.¹³

Mayer et al also examined the validity of the DI method via comparison with radiography. The two techniques were performed on twelve subjects with low back pain in standing lumbar flexion and extension. The landmarks for the radiographic measurements were lines parallel to the superior surface of S₁ and the inferior surface of T₁₂. The mean lumbar motion obtained with the DI method was reported as $60.5^{\circ} \pm 16.7^{\circ}$ and for radiography, 58.5° . The authors concluded there was no difference between the two techniques, thus validating the DI method.

Finally, Mayer et al reported normal values for standing lumbar flexion and extension using the DI technique. Thirteen subjects were measured. The results were

as follows: mean lumbar flexion ($55^{\circ} \pm 9.2^{\circ}$) and mean lumbar extension ($27^{\circ} \pm 12.8^{\circ}$).¹³

Keeley et al performed two studies involving double mechanical inclinometers. First they examined the reliability of the technique for the assessment of lumbar flexion and extension and reported normal values. Secondly, they performed a pilot study examining the reliability of the DI technique for the assessment of lumbar rotation.³⁴

The first study involved examination of two subject groups by two examiners. Group I, the non-blind group, consisted of 11 normal subjects and nine subjects with LBP. The examiners compared results after each measurement, thus allowing learning to occur. Group II, the blind group, consisted of 20 normals and 23 LBP patients. The examiners had no knowledge of the other's measurements in the second group.

The reference points chosen were the T_{12} - L_1 spinous processes and the sacrum. Subjects were measured in standing for both lumbar flexion and extension. Two measurements were taken/subject by each examiner. Inter- and intraexaminer reliabilities were then calculated.

Results were reported for the value obtained at each reference point. The interexaminer reliability estimates ranged from $r = .90$ -.96 for the value obtained at the T_{12} - L_1 reference point for both groups. The estimates for the sacral reference point were lower and ranged from $r = .74$ -.96, with the reliability estimates being lower for the blind group. Intraexaminer reliability estimates were high for both examiners, ranging from .90-.98 for the T_{12} - L_1 point and from .91-.98 for the sacral point.

The normal values reported for lumbar flexion were $65^{\circ} \pm 8.2^{\circ}$ for men and $64.4^{\circ} \pm 8.2^{\circ}$ for women. Lumbar extension normal values were $26.6^{\circ} \pm 10.8^{\circ}$ for men and $27.3^{\circ} \pm 8.5^{\circ}$ for women.³⁴

The second study involved the measurement of lumbar rotation in twenty subjects (eight patients and twelve normals). Each subject stood in a position of forward flexion until the T₁₂-L₁ level was at 90 degrees with the legs straight. With the sacral inclinometer representing the neutral position, the subject rotated to the left and then to the right with arms crossed over the chest. The difference between the two inclinometer readings represented the degree of lumbar rotation.

Only one measurement was taken by each therapist for the twenty subjects. The interexaminer reliability estimates for left and right rotation for the normal subjects were .62 and .15 respectively, and for patients were .95 and .66 respectively.

Some possible explanations offered for the poor results obtained in the second study included the small sample size, the fact that the neutral point was determined by the subjects, instability in the testing position, the small degree of lumbar motion and the use of relatively crude measurement devices. The authors did suggest however, that a more accurate measurement device could improve the results for the measurement of lumbar rotation.³⁴

Gill et al assessed the repeatability of the double inclinometer technique for the assessment of standing and sitting lumbar flexion, erect posture and lumbar extension.¹⁹ Ten normal subjects were measured on two occasions in both standing and sitting by one examiner in one day. The landmarks included the spinous processes of T₁₂-L₁ and

the sacrum. Individual Coefficient's of Variation (CV's) were reported for both the upper and lower inclinometer readings. The results were as follows: upper inclinometer CV's for standing flexion, erect, extension (33.9%, 2.3%, 3.6%), upper inclinometer CV's for sitting flexion, erect, extension (27.3%, 4.3%, 2.8%), lower inclinometer CV's for standing flexion, erect, extension (9.3%, 1.7%, 4.7%) and lower inclinometer CV's for sitting flexion, erect, extension (6.9%, 6.2%, 4.4%).

The authors concluded that the double inclinometer technique is both repeatable and reliable for quantifying functional improvements in difficult patients. They did advise caution however because inter-observer variability was not addressed.¹⁹

Klein et al examined the reliability of the double inclinometer technique for the assessment of lumbar flexion and extension as part of a larger study. Twenty five men (16 normal and 7 with LBP) were measured in standing using the spinous processes of L₁ and S₁ as reference points. Each subject was measured twice by one examiner. The intraexaminer reliability estimates for lumbar flexion and extension were .89 and .82 respectively. The authors concluded that the DI method was a reliable means to assess lumbar ROM.²⁰

Finally, Williams et al examined the double inclinometer method for the assessment of standing lumbar flexion and extension.²⁵ Fifteen subjects with chronic low back pain were measured by three therapists. One measurement was taken by each examiner on two separate days. The reference points chosen were the inferior borders of the PSIS's (a line drawn horizontally in midline) and a point 15 cm superior.

The test-retest reliability correlation coefficients reported for lumbar flexion and extension were .87, .76, .13 and .28, .66, .55 respectively for each of the three examiners. The Intraclass Correlation Coefficients for inter-rater reliabilities were .60 for lumbar flexion and .48 for lumbar extension.

The authors addressed the dissimilarity between their results and those of Keeley et al³⁴. They felt that the random testing order in their study could have led to the low reliability estimates. They also concluded that the subjects accounted for most of the variation between measurements, and that further training and instruction would be necessary to improve the reliability of the DI method.²⁵

Thus far all the studies assessing the reliability and/or validity of the inclinometer for the assessment of spinal ROM have examined the mechanical inclinometer^{13,18-20,25,27,32-37,40,41}. Similar problems have been identified with this instrument as have been identified with other potential spinal assessment devices. Inconsistencies in the methods employed, in combination with subject variability have led to conflicting results regarding the reliability of all proposed spinal assessment devices.

A final instrument that has been cited for its potential value in spinal assessment is the electronic inclinometer.³⁸⁻⁴¹ Few studies have been performed regarding the reliability or validity of this device.³⁸

Stude et al examined the intra- and interexaminer reliability of a single digital inclinometer, the Orthoranger II, for the measurement of lumbar flexion, extension, and lateral flexion.³⁸ Twenty eight asymptomatic subjects were measured two times by

two examiners for each motion. Each subject was measured on two separate occasions within the same day by each examiner. The landmarks included the spinous process of T₁₂ and the midline position of the S₁ tubercle. Separate trained research assistants palpated and marked the landmarks prior to the measurement using indelible ink to minimize any error associated with palpation.

The subjects performed three repetitions of lumbar flexion, extension, left lateral flexion and right lateral flexion. The average of the measurements was used to represent the true lumbar motion. Intraexaminer reliability estimates for examiner 1, reported in Intraclass Correlation Coefficients (ICC's) were .46, .81, .69 and .78 for lumbar flexion, extension, left lateral flexion and right lateral flexion respectively. ICC's for examiner 2 were .25, .76, .04, and .24 respectively. Interexaminer reliability estimates, reported in ICC's were .07, .81, .05, .33 (occasion #1) and .16, .83, .03 and .15 (occasion #2) for lumbar flexion, extension, left lateral flexion and right lateral flexion respectively.

The authors concluded that the Orthoranger II was not reliable in the measurement of lumbar spine ROM. Although the ICC values obtained for flexion fell within the reliable range, the authors felt that this might be explained due to limitations of the instrument. The Orthoranger II only records flexion values to 90 degrees. Any value above 90 degrees is displayed as a -1. In this study, values displayed as -1 were recorded as 90 degrees. Thus, the high ICC values could have been due to limitations with the instrument itself rather than because of true instrument reliability.³⁸

Thus, even though not much data is available regarding the electronic inclinometer³⁸, it is clear that this instrument too has problems. The purpose of this study was to examine the intra- and interrater reliability of the Saunders Electronic Inclinometer (SEI), an instrument designed specifically for the measurement of the spine, for the assessment of lumbar flexion, extension, lateral flexion and rotation.³⁹

The AMA: Guides to the Evaluation of Permanent Impairment advocates using either mechanical or electronic inclinometers for the assessment of spinal mobility.⁴⁰ This reference outlines guidelines for using both single and double inclinometer methods (mechanical or electronic) for measuring cervical, thoracic and lumbosacral mobility.

For the purposes of this research study however, only the lumbosacral techniques (flexion, extension and lateral flexion) will be examined. This study will examine the single inclinometer method only.

The recommended reference points for all lumbosacral measurements are the spinous process of T₁₂ and the sacral midpoint. The AMA: Guides to the Evaluation of Permanent Impairment has suggested that each motion be measured at least three times to assure reliability, and that the true angles be within $\pm 10\%$ or 5 degrees of one another, whichever is greater.

The recommended single inclinometer method for assessing lumbosacral flexion and extension begins with the subject in relaxed standing. This is considered the neutral, or starting position and the position from which the inclinometers are zeroed. The subject then flexes forward or extends backwards maximally. The sacral

measurement is taken first followed by movement of the inclinometer to the T₁₂ landmark where the second measurement is taken. The sacral reading is subtracted from the T₁₂ reading to obtain the true lumbar flexion or extension angles.

The test for validity recommended for lumbosacral flexion and extension involves comparing the tighter straight leg raising (SLR) angle to the sum of the sacral (hip) flexion and extension angles. The SLR angle is measured in supine by placing one inclinometer on the tibial tuberosity. If the tighter SLR angle exceeds the sum of the sacral flexion and extension angles by more than 15 degrees, the lumbosacral flexion and extension tests are considered invalid.

The single inclinometer method recommended for assessing lumbosacral lateral flexion also begins with the subject in relaxed standing. This is considered the neutral position and the position from which the inclinometers are zeroed. Since the motion occurs in the coronal plane, the inclinometer is positioned likewise. With the subject in maximal lateral flexion, a reading is first taken at the sacral reference point. The inclinometer is then moved to the T₁₂ reference point and a second reading is taken. The actual lateral flexion angles are obtained by subtracting the two readings.

Although the inclinometer techniques presented in the AMA: Guides to the Evaluation of Permanent Impairment potentially provide more accurate assessments of spinal mobility,⁴⁰ there has been some controversy as to the methods advocated. Specifically, Saunders questions the use of relaxed standing as the point from which to zero the inclinometers.³⁹

Saunders advocates using a standard zero position such as the top or underside of a table, rather than zeroing on each subject individually. The author argues that zeroing the inclinometer on each subject is highly variable, thus making comparison between subjects less reliable. A subject whose resting posture is in slight forward flexion for example, might not be able to achieve a neutral spinal posture. According to the AMA guidelines however, the subject's resting posture would be the zero point.⁴⁰ Thus, an individual might have the flexibility to extend, but their end range could still be in forward flexion. Following AMA guidelines, that individual might be assessed as having 10 degrees of spinal extension, when in fact they actually remain in 10 degrees of forward flexion.³⁹

Saunders has developed an electronic inclinometer specifically for the assessment of spinal motion.³⁹ The author has proposed standardizing the zero position which should theoretically improve the reliability of the device. Remaining consistent with the AMA guidelines,⁴⁰ Saunders has presented both single and double inclinometer techniques. The author specifies methods for assessing cervical, thoracic and lumbar mobility.

For the purposes of this research study, only the lumbar techniques (flexion, extension, lateral flexion, and rotation) will be examined using the single inclinometer method. To date, there have been no published studies documenting the reliability of this device.

Hypothesis

The hypothesis of this study is that the Saunders Electronic Inclinometer will demonstrate good intrarater and interrater reliability for the measurement of standing lumbar flexion, extension, lateral flexion and rotation.

CHAPTER 2

METHODS

Subjects

Twenty two students from the Physical Therapy Program at Old Dominion University voluntarily participated in the study. There were four males and 18 females ranging in age from 22 to 35 years (25.23 ± 3.65). Eighteen subjects (15 females, 3 males) were healthy with no history of low back pain, musculoskeletal or neurological problems. Three of the subjects (2 females, 1 male) had histories of chronic low back pain (>6 month duration). One female, presently asymptomatic, underwent low back surgery during childhood. All subjects gave written informed consent prior to participation in the study.

The study was approved by the Human Subjects Committee, School of Community Health Professions and Physical Therapy, Old Dominion University.

Instrumentation and Procedure

Data was collected using the Saunders Electronic Inclinometer (SEI).^{*} One SEI was used to collect a series of lumbar measurements. The inclinometer was calibrated prior to each measurement by zeroing the instrument on a table top or bottom. Data was collected according to the SEI Operator's Manual.

^{*} The Saunders Group, Inc. *Saunders Electronic Inclinometer*. Chaska, Minnesota. 55318; 1994.

Two examiners participated in the study including a final year physical therapy student (TB) at Old Dominion University and a physical therapist (MM) with 8 years of neurologic and orthopedic experience. Examiner 2 (MM) had 3 years of clinical experience with the electronic inclinometer prior to the initiation of the study. To standardize the protocol for performing measurements, the SEI Operator's Manual was reviewed by both examiners. A pilot study was then performed one week prior to the study. Four asymptomatic subjects were measured. Patient starting positions, landmarks, movement positions, and examiner commands were standardized. The results obtained in this study therefore, should be generalized only to those examiners undergoing similar training to assure use of a standard protocol.

A series of 6 lumbar movements was measured on each subject including flexion, extension, right lateral flexion, left lateral flexion, right rotation and left rotation. Each subject was measured by 2 examiners (TB and MM) on 2 separate days (1 week interval between days). Thus, on the first day of testing each subject was measured 12 times. On the second day of testing, another 12 measurements were taken.

The subjects performed 3 warm-up repetitions per movement prior to the actual measurement. The same series of lumbar movements (flexion, extension, right lateral flexion, left lateral flexion, right rotation, left rotation) was performed by each of the subjects. The subjects were measured in the same order, using the same sequence of movements on both days. They were first measured by TB and then by MM. Data collection for each series of movements took approximately 3-5 minutes.

Each subject was asked to stand with feet shoulder width apart in a relaxed standing posture. Subjects remained in flat street shoes and were asked to expose their lumbar spines from below the PSIS levels to the mid-thoracic spine. The subjects then performed 3 warm-up repetitions for each of the 6 movements.

Lumbar Flexion

The examiner knelt behind the standing subject and marked 2 landmarks on the skin using removable dots. First, the examiner palpated the inferior margins of the PSIS levels. This represented the S_2 spinous level. The skin was then marked horizontally along the midline of the spine. Secondly, the examiner palpated the inferior margins of the lower ribs. This represented the T_{12}/L_1 junction. Again, the skin was marked horizontally along the midline of the spine.

The SEI was first zeroed on the top of a table. The subject was then asked to perform maximal standing flexion sliding their hands down their thighs attempting to reach their toes. The SEI was first placed perpendicular to the S_2 point and then moved perpendicular to the T_{12}/L_1 point. Readings were taken at each point by the examiner. Results were recorded by a third person. The difference between the 2 readings indicated lumbar flexion.

Lumbar Extension

The SEI was first zeroed on the top of a table. The subject was then asked to perform maximal standing extension with their arms folded across their chest attempting to look up at the ceiling. The SEI was first placed perpendicular to the S_2 point and then moved perpendicular to the T_{12}/L_1 point. Readings were taken at each point by the

examiner. Results were recorded by a third person. The difference between the 2 readings indicated lumbar extension.

Lumbar Lateral Flexion

The ruler attachment was added to the SEI. Two additional dots were added to the S_2 point and to the T_{12}/L_1 point forming a straight line with which to align the SEI. The SEI was first zeroed on the top of a table. The subject was then asked to perform maximal standing lateral flexion, first to the right and then to the left. The subject performed the movement by sliding their hand down the outside of their respective leg. The ruler attachment of the SEI was placed perpendicular to the spine, first along the line at the S_2 point and then along the line at the T_{12}/L_1 point. Readings were taken at each point by the examiner. Results were recorded by a third person. The difference between the 2 readings indicated right and left lumbar lateral flexion respectively.

Lumbar Rotation

The SEI was first zeroed underneath a table. The subject was then asked to perform maximal standing rotation, first to the right and then to the left. The subject folded their arms across their chest, held their hips at ninety degrees of flexion with their knees straight, and with their trunk parallel to the floor. The subject then performed right and left rotation attempting to look up over their respective shoulder. The ruler attachment of the SEI was placed perpendicular to the spine, first along the line at the S_2 point and then along the line at the T_{12}/L_1 point. Readings were taken at each point by the examiner. Results were recorded by a third person. The difference between the 2 readings indicated right and left lumbar rotation respectively.

Skin dots were then removed and the subject performed the same series of movements with the second examiner performing the measurements. This concluded the first day of measuring. The exact same sequence of measuring was followed one week later. Results were then analyzed.

Data Analysis

Analysis of variance (ANOVA)-derived Intraclass Correlation Coefficient's were used to determine the intrarater (3,1) and interrater (2,1) reliability for standing lumbar flexion, lumbar extension, right and left lumbar lateral flexion, and right and left lumbar rotation.⁴³ The standard error of measurement (SEM) was calculated for the above lumbar movements. 95% Confidence Intervals were then constructed for the intrarater and interrater reliability data. Lastly, Coefficients of Variation were calculated to determine subject variability.

CHAPTER 3

RESULTS

Table 1 includes standing lumbar flexion, extension, right and left lateral flexion, and right and left rotation ROM data obtained by each therapist individually and by both therapists combined. The mean, standard deviation and range is presented for each lumbar movement.

Tables 2 and 3 include the Analysis of Variance-Derived Intraclass Correlation Coefficients for intrarater and interrater reliability measurements respectively. The intrarater reliability ICC's (3,1) for therapist one were .71, .76, .55, .44, .58, and .88 for lumbar flexion, extension, right lateral flexion, left lateral flexion, right rotation and left rotation. The intrarater reliability ICC's (3,1) for therapist two were .82, .66, .71, .74, .71, and .75 for the above movements respectively. The interrater reliability ICC's (2,1) were .79, .60, .46, .38, .46, and .70 for lumbar flexion, extension, right and left lateral flexion and right and left rotation respectively.

Table 4 contains 95% Confidence Intervals (CI's) for each of the six lumbar movements. Intrarater and interrater reliability data are included. The Standard Error of Measurement (SEM) was calculated for each movement. This value was used with the respective ICC to determine the 95% CI.

Table 5 contains Coefficients of Variation (CV) for the interrater data. The CV's were 54.6% for lumbar flexion, 30.4% for extension, 28.3% for right lateral flexion, 36.4% for left lateral flexion, 87.1% for right rotation and 73% for left rotation.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Our study investigated the Saunders Electronic Inclinometer³⁹ (SEI) for the measurement of standing lumbar flexion, extension, lateral flexion and rotation. This device was developed specifically for the assessment of spinal motion.

Portney and Watkins suggest the following reliability coefficients for the determination of clinical usefulness of a measurement device. Coefficients $>.75$ demonstrate good reliability, $.50 - .75$ demonstrate moderate reliability, and $<.50$ demonstrate poor reliability.⁴³ The authors suggest that even a measurement device with moderate reliability can add sufficient information to justify its use, especially if that device is used in conjunction with other tests.

In our study, 22 individuals (18 normal, 4 symptomatic) were assessed on two separate days by each of two examiners. Examiner one had one month of experience with the SEI while examiner two had three years of experience with the SEI. ANOVA-derived ICC's (3,1) for intrarater reliabilities ranged from moderate to good for flexion (.71-.82), moderate to good for extension (.66-.76), moderate for right lateral flexion (.55-.71), poor to moderate for left lateral flexion (.44-.74), moderate for right rotation (.58-.71) and good for left rotation(.75-.88).

As expected, interrater reliability estimates were lower. ANOVA-derived ICC's (2,1) for interrater reliabilities were good for flexion (.79), moderate for extension (.60),

poor for right and left lateral flexion (.46 and .38), poor for right rotation (.46) and moderate for left rotation (.70).

Thus, our results are variable like the work of many preceding authors.^{13,18-20,25,27,32-34,38} This is due in part, to the difficulty of measuring the spine secondary to its anatomy. It is impossible to completely isolate spinal motion. Subject variation is also an important factor contributing to variable results.

In our study, subject variability was high. This is demonstrated by the high Coefficients of Variation (CV's). Using the interrater reliability data, the CV's were as follows: 54.6% for lumbar flexion, 30.4% for extension, 28.3% for right lateral flexion, 36.4% for left lateral flexion, 87.1% for right rotation, and 73% for left rotation. Since the CV is defined as the standard deviation expressed as a percentage of the mean, this statistic is an indication of the variability within the subjects.⁴² Because subject variability is so high for spinal ROM measurements, the examiner must make a professional judgment regarding true patient effort based on several other factors including, subject motivation, movement patterns, strength, and neurologic signs.

In addition, other factors such as subject starting position, subject perceived maximal effort, and palpation of landmarks undoubtedly affected the results of this study. It is clear that many variables can affect the outcome of performing spinal measurements. Thus, it is imperative that clinicians standardize a protocol to assure consistent use of the same measurement method.

We attempted to minimize external sources of error by standardizing the measurement protocol. Both examiners read and practiced the protocol for using the SEI.

A pilot study was performed one week prior to the commencement of the study. Both examiners assured the use of standard landmarks, commands and subject positions at that time.

Our study attempted to simulate a clinical setting as closely as possible. The subjects were measured on two occasions at one week intervals at exactly the same time on both days. Three warm-up repetitions were performed prior to the initiation of testing. Each subject first performed one measurement series for examiner one and then a second measurement series for examiner two. Each examiner palpated and marked their own landmarks. The sequence of performing the movements remained the same. Subjects were instructed not to change their exercise routines during the course of the study. Thus, under ideal conditions, one would expect the measurements to remain the same on both days of testing. This did not occur.

Regardless of attempts to control for external sources of error, our results suggest that the SEI is not reliable for the assessment of lateral flexion and right rotation. It does demonstrate moderate to good reliability however, for the assessment of standing lumbar flexion, extension and left rotation. Two possible reasons for the conflicting rotation measurements are the subject difficulty in maintaining the end-range position and the small degree of ROM available when performing lumbar rotation. Even a slight error could produce unreliable results. Thus, we partially accept our hypothesis that the Saunders Electronic Inclinator would demonstrate good intrarater and interrater reliability for the measurement of standing lumbar flexion, extension, lateral flexion and rotation.

The AMA: Guides to the Evaluation of Permanent Impairment recommends that the inclinometer, mechanical or electronic, be used for the assessment of spinal ROM.⁴⁰ It does not however, specify which device is preferred. Guidelines have been established for the measurement of cervical, thoracic and lumbosacral movements using either the single (SI) or the double (DI) inclinometer technique.

The literature is very confusing with regard to which device is the most reliable.^{13,18-20,25,27,32-34,38} Mayer et al found no difference between the SI and DI methods in the assessment of standing lumbar flexion and extension. They also concluded that the DI method was valid via comparison with radiograph.¹³ Keeley et al found the DI method to be reliable for measuring standing lumbar flexion and extension. A pilot study showed the DI method to be promising for the measurement of lumbar rotation.³⁴

Merritt et al concluded that the SI technique was reliable for the measurement of sitting flexion but not for prone extension.¹⁸ Gill et al found the DI method to be reliable for measuring both standing and sitting lumbar flexion, erect lumbar posture and lumbar extension when used by one examiner.¹⁹

Williams et al found the DI method demonstrated questionable reliability in the assessment of standing lumbar flexion and extension.²⁵ Breum et al concluded that the BROM II, a modified single inclinometer designed specifically for the spine, demonstrated good reliability for standing lumbar flexion and lateral flexion measurements. Standing lumbar extension and rotation measurements however, demonstrated poor reliability.³³

Previously, all the aforementioned studies involved the use of the mechanical inclinometer. The one study most similar to ours in that it examined an electronic

inclinometer, the Orthoranger II, produced very conflicting results in comparison with ours. Stude et al reported interrater reliability estimates for two measurement occasions ranged from (.81 - .83) for flexion, (.07 - .16) for extension, (.15 - .33) for right lateral flexion and (.03 - .05) for left lateral flexion.³⁸ The authors discounted the flexion results secondary to an intrinsic limitation with the Orthoranger II. Thus, they reported that this device was unreliable for the measurement of standing lumbar flexion, extension and lateral flexion. Our results are more promising. Our study found the SEI to be reliable for the measurement of standing lumbar flexion, extension and left rotation. Lateral flexion and right rotation demonstrated poor reliability. Some possible explanations for the differences between the two studies include our use of warm-up repetitions to minimize increases in flexibility over time and our use of an electronic device designed specifically to accommodate measuring spinal motion.

Thus, regardless of the number, type or design of the inclinometer, several studies have produced variable results in the measurement of the lumbar spine.^{13,18-20,25,27,32-34,38} Much of this variability is due to difficulty isolating spinal motion, subject variation in maintaining end range positions and examiner variability in palpating landmarks. Our study clearly had a fourth factor which affected the results, examiner experience using the measurement device.

We attempted to discount for the difference in experience by providing a one month training period and a pilot study prior to the initiation of our study. The intrarater reliability estimates for examiner one however, with one month of experience with the SEI, ranged from poor to good (.44 - .88). Intrarater reliability estimates for examiner

two, on the other hand, with three years of experience with the SEI, were more consistent ranging from moderate to good (.66 - .82). The ICC values reported for examiner two were clearly more stable than those reported for examiner one indicating that experience level clearly affected the results of this study.

One study that produced similar results to ours was that of Breum et al.³³ The authors examined the reliability of the BROM II for measuring standing lumbar flexion, extension, lateral flexion and rotation. This was the only study found that examined all four motions of the lumbar spine. ICC's for intrarater/interrater reliability estimates were (.91, .77) for flexion, (.63, .35) for extension, (.56, .37) for left rotation, (.57, .35) for right rotation, (.92, .81) for left lateral flexion and (.89, .89) for right lateral flexion. The authors concluded that the BROM II was reliable for the assessment of lumbar flexion and lateral flexion but not for lumbar extension and rotation. We found the SEI to be reliable for flexion, extension and left rotation but unreliable for lateral flexion and right rotation. Some dissimilarities with our study include using the same landmarks between examiners, measuring only healthy subjects and performing all measurements on one testing day. These similar but conflicting results are probably the result of differences in the methods employed in each of the studies. This clearly demonstrates the need to standardize a protocol for assessing spinal ROM.

Williams et al examined the DI technique using 15 symptomatic subjects for the assessment of standing lumbar flexion and extension.²⁵ The authors varied the landmarks slightly (PSIS levels and a point 15 cm superior) and they were removed after each examiner. No warm-up repetitions were performed. The authors concluded that the DI

method demonstrated questionable reliability for standing lumbar flexion ($ICC = .60$) and for standing lumbar extension ($ICC = .48$). Our results were slightly higher, standing lumbar flexion ($ICC = .79$) and standing lumbar extension ($ICC = .60$). These differences could be accounted for in part due to their measurement of all symptomatic patients, a difference in landmarks, and the use of a mechanical vs. an electronic inclinometer. Again, there are subtle differences in the methods used in the two studies.

Clinical Implications

Measurement of spinal ROM has presented a challenge to clinicians for many years. The AMA has suggested using either a mechanical or an electronic inclinometer for the measurement of this motion.⁴⁰ This allows the clinician to report separate cervical, thoracic and lumbar motions in degrees. This facilitates better documentation of problem areas as well as progress with treatment. Unfortunately, even though the AMA has recommended the use of the inclinometer, no standard protocol has been agreed upon. This has caused extreme confusion for clinicians treating individuals with spinal problems.

Our study produced conflicting results with regard to using the SEI for the measurement of lumbar motion. This has traditionally been the case with attempts to measure spinal motion over the years. No single device or measurement protocol has been agreed upon as the standard. As a result, there are many devices used in different clinics with variable results.

Our study has identified four controllable factors that influence the reliability of measuring the lumbar spine. These include inconsistent use of landmarks, inconsistent

subject starting and ending positions, inconsistent types of inclinometer used, and inconsistent examiner training periods.

Our study found a significant difference between intrarater reliability estimates depending on the level of experience of the examiner. The estimates for examiner one with one month of experience with the SEI were variable ranging from poor to good while the estimates for examiner two were more consistent ranging from moderate to good. Examiner two had been using the SEI for three years in the clinic. The findings of examiner two may actually represent a more accurate portrayal of the SEI's reliability. If this is in fact true, this would dictate the need for an adequate training period with the SEI. Perhaps experience levels of the examiners, both as a clinician and with the measurement device, has also affected the results of preceding studies. Examiner one was a final year physical therapy student while examiner two had 8 years of clinical experience. This undoubtedly had an impact on the interrater reliability results.

Portney and Watkins suggest that even instruments demonstrating moderate reliability can be clinically useful when used in conjunction with other tests.⁴³ The spine is clearly difficult to measure. Enough studies have been performed documenting variable results with regard to measuring spinal ROM to conclude that one measurement device will probably never demonstrate high reliability at all times. Regardless of these drawbacks however, examiners must minimize the external errors associated with measuring the spine. A protocol standardizing landmarks, subject positions and measurement device must be established. Normal values for that measurement protocol should then be established.

The AMA supports the use of inclinometers for the measurement of spinal motion⁴⁰ but conflicting results have been reported with regard to their use. Some authors support the use of inclinometers^{13,18,19,33,34} while others do not.^{18,25,33,38} The only advantage for using the electronic inclinometer appears to be its ability to display spinal position digitally. The mechanical inclinometer appears superior at this point with regard to its reliability. The electronic inclinometer requires more investigation before one device can be deemed more reliable than another.

Our society spends a tremendous amount of money on the prevention and treatment of low back injuries. These costs could be better controlled if the health care community could agree upon and use one standard measurement method for assessing spinal motion. This, in conjunction with other tests such as measurements of strength and functional limitations, would afford more accuracy in the diagnosis and treatment of individuals with spinal disorders.

Future Study

Further studies need to be performed investigating the Saunders Electronic Inclinometer (SEI) and its reliability in the assessment of spinal posture and ROM. Our study only investigated the motions of the lumbar spine. The SEI was specifically designed for measuring the cervical, thoracic and lumbar spines.³⁹ Future studies could investigate cervical and thoracic motions or the measurement of lumbar spinal motion could be repeated. The authors recommend use of the same measurement protocol as outlined in their study. They also recommend using examiners with similar levels of

clinical experience as well as similar levels of training with the SEI. Due to the sensitivity of this instrument and the difficulty in measuring the spine, experience level does appear to yield more reproducible results.

Secondly, our study did not address the validity of the SEI technique. Mayer et al examined 12 patients, comparing the DI technique with radiography, and concluded that the DI technique was valid.¹³ The authors have chosen to argue the validity of the SEI for measuring spinal motion based on the work of Mayer et al.¹³

Finally, if the reliability of the SEI becomes established, normal values for cervical, thoracic and lumbar ROM should be collected. These values should be collected in 10 year intervals and differences related to gender should be identified.

Conclusions

The Saunders Electronic Inclinometer (SEI) was investigated as a potential measurement device for measuring the lumbar spine. Our results indicate that this device is reliable for the measurement of standing lumbar flexion, extension, and left rotation. This instrument was found to demonstrate poor reliability however, in the assessment of standing lumbar lateral flexion and right rotation. Caution should be used however in the interpretation of these results because experience level of the examiners appears to have impacted our results.

There are several external sources of error which must be controlled for to negate their effect on the reliability estimates of measuring this motion. Experience level, both clinically and using the SEI, appear to effect the reliability of its use. Experience using this

instrument minimizes error associated with its high level of sensitivity. The intrarater reliability estimates for examiner two ranged from moderate to good for standing lumbar flexion, extension, lateral flexion and rotation. Thus, according to Portney and Watkins this measurement method could provide valuable information when used in conjunction with other tests.⁴³

In conclusion, the authors note that testing conditions must be ideal in order for measurements of the spine to demonstrate good reliability at all times. The SEI, designed specifically for measuring spinal motion, minimizes intrinsic errors associated with the measurement device. The SEI is a simple, cost effective method for measuring the spine that warrants further investigation.

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Table 1.

Group Means and Standard Deviations for Lumbar Motion (in Degrees) Using the Saunders Electronic Inclinometer

Movement (in degrees)	Rater	Mean	SD	Range
Lumbar flexion	1	14.59	7.76	2 - 28
	2	15.86	8.17	1 - 34
	1 & 2	15.43	8.42	1 - 34
Lumbar extension	1	46	10.97	24 - 68
	2	42.36	12.94	14 - 64
	1 & 2	42.64	12.97	14 - 68
Lumbar right lateral flexion	1	15.66	4.37	7 - 25
	2	14.05	3.91	5 - 21
	1 & 2	13.98	3.96	5 - 25
Lumbar left lateral flexion	1	16.3	4.87	5 - 27
	2	13.07	4.97	0 - 24
	1 & 2	14.27	5.2	0 - 27
Lumbar right rotation	1	5.5	3.4	0 - 13
	2	3.27	3.96	-3 - 14
	1 & 2	4.25	3.7	-3 - 14
Lumbar left rotation	1	4.86	3.67	-1 - 15
	2	5.84	4.02	-2 - 17
	1 & 2	5.23	3.82	-1 - 17

Table 2.

Analysis of Variance-Derived Intraclass Correlation Coefficients
(3,1) for Lumbar Motion Measured Using the Saunders
Electronic Inclinometer

Movement	Rater 1	Rater 2
	ICC^a	ICC^b
Lumbar flexion	0.71	0.82
Lumbar extension	0.76	0.66
Lumbar right lateral flexion	0.55	0.71
Lumbar left lateral flexion	0.44	0.74
Lumbar right rotation	0.58	0.71
Lumbar left rotation	0.88	0.75

^a Significant at $P < .02$

^b Significant at $P < .001$

Table 3.

Analysis of Variance-Derived Intraclass Correlation Coefficients (2,1) for Lumbar Motion Measured Using the Saunders Electronic Inclinator

Movement	ICC
Lumbar flexion	0.79 ^a
Lumbar extension	0.60 ^a
Lumbar right lateral flexion	0.46 ^b
Lumbar left lateral flexion	0.38 ^c
Lumbar right rotation	0.46 ^a
Lumbar left rotation	0.70 ^a

^a Significant at $P < .001$

^b Significant at $P < .007$

^c Significant at $P < .01$

Table 4.

95 % Confidence Intervals for Lumbar Motion (in Degrees) Using the Saunders Electronic Inclinometer

Movement (in degrees)	Rater	SEM^a	95 % CI^b
Lumbar flexion	1	4.18	6.23 - 22.95
	2	3.47	8.92 - 22.80
	1 & 2	3.86	7.71 - 23.15
Lumbar extension	1	5.37	35.26 - 56.74
	2	7.55	27.26 - 57.46
	1 & 2	8.2	26.24 - 59.04
Lumbar right lateral flexion	1	2.93	9.8 - 21.52
	2	2.1	9.85 - 18.25
	1 & 2	2.91	8.15 - 19.81
Lumbar left lateral flexion	1	3.64	9.02 - 23.58
	2	2.53	8.01 - 18.13
	1 & 2	4.09	6.09 - 22.45
Lumbar right rotation	1	2.2	1.10 - 9.90
	2	2.13	-.99 - 7.53
	1 & 2	2.72	-1.19 - 9.69
Lumbar left rotation	1	1.27	2.32 - 7.40
	2	2.01	1.82 - 9.86
	1 & 2	2.09	1.05 - 9.41

^a Standard Error of Measurement

^b Confidence Interval

Table 5.
Coefficients of Variation for Lumbar Motions Measured
Using the Saunders Electronic Inclinometer

Movement (in Degrees)	Rater	CV^a
Lumbar flexion	1	53.20%
	2	51.50%
	1 & 2	54.60%
Lumbar extension	1	23.90%
	2	30.60%
	1 & 2	30.40%
Lumbar right lateral flexion	1	27.90%
	2	27.80%
	1 & 2	28.30%
Lumbar left lateral flexion	1	29.90%
	2	38.00%
	1 & 2	36.40%
Lumbar right rotation	1	61.80%
	2	121.10%
	1 & 2	87.10%
Lumbar left rotation	1	75.50%
	2	68.80%
	1 & 2	73.00%

^a Coefficient of Variation